MSUGRA DARK MATTER AND THE B QUARK MASS

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We extend the commonly used mSUGRA framework to allow complex soft terms. We show how these phases can induce large changes of the SUSY threshold corrections to the b quark mass and affect the neutralino relic density predictions of the model. We present some specific models with large SUSY phases which can accommodate the fermion electric dipole moment constraints and a neutralino relic density within the WMAP bounds.

1. Introduction

The recent Wilkinson Microwave Anisotropy Probe (WMAP) data allows a determination of cold dark matter (CDM) to lie in the range[1] $\Omega_{CDM}h^2 = 0.1126^{+0.008}_{-0.009}$. In this analysis we extend the mSUGRA framework to include CP phases in the gaugino sector [2], which affects the loop corrections to the

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b quark mass and also affects the mixing between the neutral Higgs bosons. These corrections then affect relic density computations in important ways.

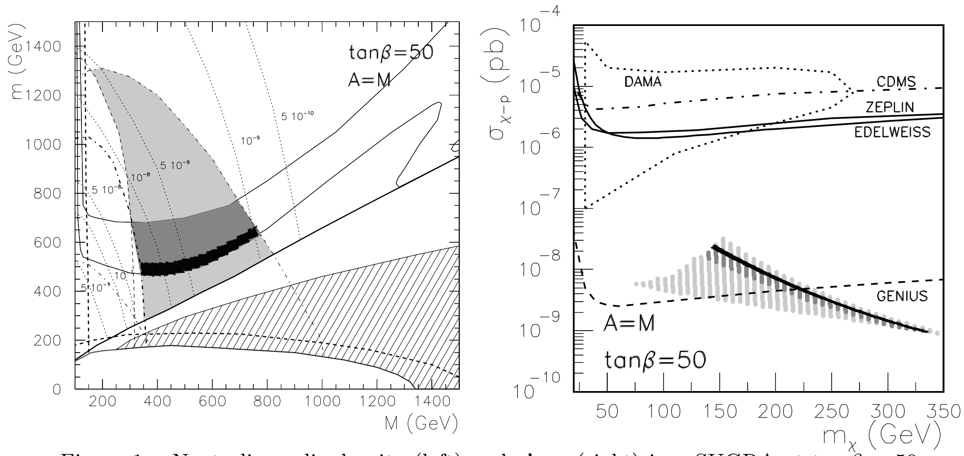

Figure 1. Neutralino relic density (left) and $\sigma_{\chi-p}$ (right) in mSUGRA at $\tan\beta = 50$. Darker areas are favored by the phenomenological constraints described in Ref. [7].

2. mSUGRA Dark Matter

In most of the mSUGRA parameter space [3] the LSP is almost purely a Bino $\tilde{B}$ with a large relic density. However, we can classify three regions where Ω_χ can reach the WMAP bounds: (i) Coannihilation region [4]: Relic abundance decreases due to coannihilations $\chi - \tilde{\tau}$ when $m_{\tilde{\tau}} \simeq m_\chi$. (ii) Hyperbolic Branch/Focus-point (HB/FP) region[5]: The μ–term is small, such that χ_0 may have large Higgsino fraction which enables a faster annihilation. (iii) Resonances on Higgs mediated channels[6]: Relic abundance constraints are satisfied by annihilation though resonant s-channel Higgs exchange. In Fig. 1, we present some representative mSUGRA predictions for $\Omega_\chi h^2$ at large $\tan\beta$[7]. In the next section we analyze the impact of enlarging this picture including CP phases using the following point in the point in the mSUGRA parameter space

$$\tan\beta = 50,\ m_0 = m_{1/2} = |A_0| = 600\,\text{GeV}. \tag{1}$$

3. Phase Generalized mSUGRA

Within mSUGRA there are only two physical phases, θ_μ, θ_A which are phases of μ and A_0. These phases must be small ($\leq 10^{-2}$) to satisfy the

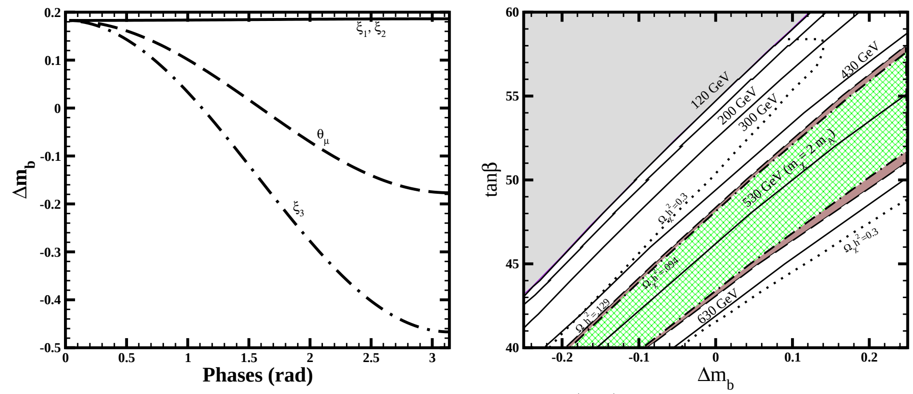

Figure 2. Δm_b as a function of the indicated phases (left) and regions allowed by the relic density constraints for the parameters on Eq. (1) of the text.

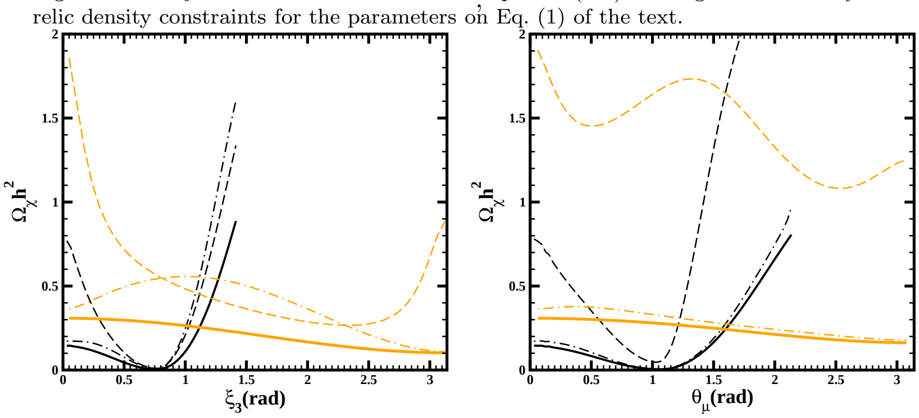

Figure 3. $\Omega_\chi h^2$ as a function of ξ_3 and θ_μ for the parameters on Eq. (1), using the theoretically predicted value of Δm_b (black lines), $\Delta m_b = 0$ (light lines). Solid lines include all contributions, dashed lines (dot-dashed lines) only s-channel H_1 (H_3) mediated annihilation to $b\bar{b}$.

electric dipole moments (EDM) constraints

$$|d_e| < 4.23\times 10^{-27}\text{ecm},\quad |d_n| < 6.5\times 10^{-26}\text{ecm},\quad C_{\text{Hg}} < 3.0\times 10^{-26}\text{cm}. \quad (2)$$

Large phases can be accommodated in several scenarios such as models with *super heavy sfermions* for the two first generations [8] or models with a non–trivial *soft term* flavor structure[9]. Here, we assume a cancellation mechanism [10] which becomes possible if we assume an extended SUGRA parameter space characterized by the parameters

$$m_0, m_{1/2}, \tan\beta, |A_0|, \theta_\mu, \alpha_A, \xi_1, \xi_2, \xi_3, \quad (3)$$

where, ξ_i is the phase of the gaugino mass M_i. The value of $|\mu|$ is determined by imposing electroweak symmetry breaking.

3.1. *Loop Correction to the b Quark Mass*

At the loop level the effective b quark coupling with the Higgs is given by[11]

$$-L_{bbH^0} = (h_b + \delta h_b)\bar{b}_R b_L H_1^0 + \Delta h_b \bar{b}_R b_L H_2^{0*} + H.c. \tag{4}$$

The correction to the b quark mass is then given directly in terms of Δh_b and δh_b so that

$$\Delta m_b = [Re(\frac{\Delta h_b}{h_b})\tan\beta + Re(\frac{\delta h_b}{h_b})]. \tag{5}$$

A full analysis of Δm_b is used[12]. Δm_b depends strongly on ξ_3 and θ_μ and weakly on α_A, ξ_1, ξ_2 as we see from the left panel of Fig. 2. The consequences for $\Omega_\chi h^2$ arising from the changes of Δm_b in this range can be understood from the qualitative analysis on the right panel of Fig. 2, where Δm_b is used as a free parameter. We observe that for a fix value of $\tan\beta$ the pseudo scalar Higgs mass can reach values in the range $m_A \sim m_\chi/2$, allowing predictions for $\Omega_\chi h^2$ [a] on the WMAP bounds.

3.2. *The Higgs sector CP–even CP–odd Mixing*

CP violating phases induce mixing at one loop of the CP–even, H, h, and CP–odd, A, neutral tree level Higgs bosons: $(H, h, A) \to (H_1, H_2, H_3)$, where H_i (i=1,2,3) are the mass eigen states. The relevant couplings[b] for the s-channel neutralino annihilation become

$$L = (S'_k + iS''_k\gamma_5)H_k\chi\chi + (C_k^S + iC_k^P\gamma_5)H_k b\bar{b}. \tag{6}$$

The resonant annihilation cross-section behaves as

$$\sigma_{\rm ann} \sim \frac{(C_k^S C_l^S + C_k^P C_l^P)\left[S'_k S'_l(1-4m_\chi^2/s) + S''_k S''_l\right]}{(-m_{H_k}^2 + s - im_{H_k}\Gamma_{H_k})(-m_{H_l}^2 + s + im_{H_l}\Gamma_{H_l})} s^2 \tag{7}$$

We observe that imaginary couplings (S'') will dominate, since the real ones are suppressed by the factor $1 - 4m_\chi^2/s$. Fig. 3 shows the changes of $\Omega_\chi h^2$ with ξ_3 and θ_μ. The long light lines are obtained by setting $\Delta m_b = 0$, which implies that the Higgs masses remain almost constant along these lines and hence we see the effects of the CP phases on the vertices without the variation due to Δm_b. Also, $m_{H_1} \sim m_{H_3}$ and $\Gamma_{H_1} \sim \Gamma_{H_3}$, therefore large mixing are possible as we see in the partial contributions of H_1 (dash) and H_3 (dot–dash) mediated s–channels.

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[a]We use *micr0MEGAs* [13] for the computations of $\Omega_\chi h^2$ without phases.
[b]We use *CPsuperH* [14] in our computations.

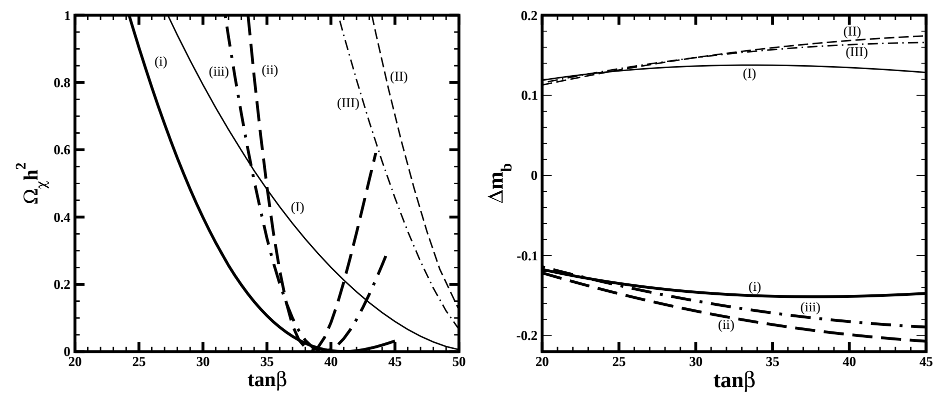

Figure 4. The neutralino relic density as a function of $\tan\beta$ for the three cases (i), (ii), (iii) of the text (left). Lines (I), (II) and (III) correspond to similar set of SUSY parameters for the case of vanishing phases. On the right we present the corresponding values of Δm_b.

4. CP–Phases, EDM's and Neutralino Relic Density

In Fig. 4 the neutralino relic density is displayed as a function of $\tan\beta$ for three cases given by: (i) $m_0 = m_{1/2} = |A_0| = 300$ GeV, $\alpha_{A_0} = 1.0$, $\xi_1 = 0.5$, $\xi_2 = 0.66$, $\xi_3 = 0.62$, $\theta_\mu = 2.5$; (ii) $m_0 = m_{1/2} = |A_0| = 555$ GeV, $\alpha_{A_0} = 2.0$, $\xi_1 = 0.6$, $\xi_2 = 0.65$, $\xi_3 = 0.65$, $\theta_\mu = 2.5$; (iii) $m_0 = m_{1/2} = |A_0| = 480$ GeV, $\alpha_{A_0} = 0.8$, $\xi_1 = 0.4$, $\xi_2 = 0.66$, $\xi_3 = 0.63$, $\theta_\mu = 2.5$. In all cases the EDM constraints (2) are satisfied for $\tan\beta = 40$ and their values are exhibited in table 1. We also observe that the WMAP bounds are also satisfied in the range of $\tan\beta$ exhibited in Fig.4.

Table 1. The EDMs for $\tan\beta = 40$ for cases of text.

Case	$\|d_e\| e.cm$	$\|d_n\| e.cm$	$C_{Hg} cm$
(i)	2.74×10^{-27}	1.79×10^{-26}	8.72×10^{-27}
(ii)	1.29×10^{-27}	1.82×10^{-27}	6.02×10^{-28}
(iii)	9.72×10^{-28}	4.19×10^{-26}	1.41×10^{-27}

5. Conclusions

The SUSY threshold correction to m_b, Δm_b, can induce large changes on the two heavier neutral Higgs bosons. For a given m_χ and certain values of Δm_b the resonance condition $m_{H_i} \sim 2m_\chi$ can be satisfied. This implies a neutralino relic density inside the WMAP bounds. Δm_b is strongly dependent on the SUSY phases ξ_3 and θ_μ. Hence, these phases can drive Ωh^2 to the WMAP region leaving the possibility of choosing the other phases such

that a cancellation mechanism keeps the fermion EDM predictions below the current experimental bounds.

Acknowledgments

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